# Feedbacks between Climate and Fire Emissions

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Tech Session 1A:
Role of Fire in the Carbon Cycle under Climate Change

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14. ABSTRACT

**Fires emit significant amounts of trace gases and particulate matter to the atmosphere. These emissions include greenhouse gases, such as CO2 and methane, reactive gases that include a suite of non-methane organic compounds, and various particulate species, including black and organic carbon. Quantifying these emissions and constraining our understanding of their impacts on the atmosphere continues to be an on-going challenge. Recent advances in measurement techniques, remote sensing observations and modeling tools have enabled much better constraints on these processes, yet, large uncertainties remain. There are feedbacks between the fire and climate systems that can control the emissions from fires. Further, once in the atmosphere, fire emissions not only impact atmospheric composition and air quality, but can also influence the climate system in various ways. For example, particulate matter emitted to the atmosphere from fires can have direct radiative effects that can influence local meteorology, as well as processes that control atmospheric chemistry. This talk will address the various emissions from fires to the atmosphere and their controls, including climatic controls. The impacts of fires on the climate system will also be highlighted and the results from recent studies presented.**

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# FEEDBACKS BETWEEN CLIMATE AND FIRE EMISSIONS

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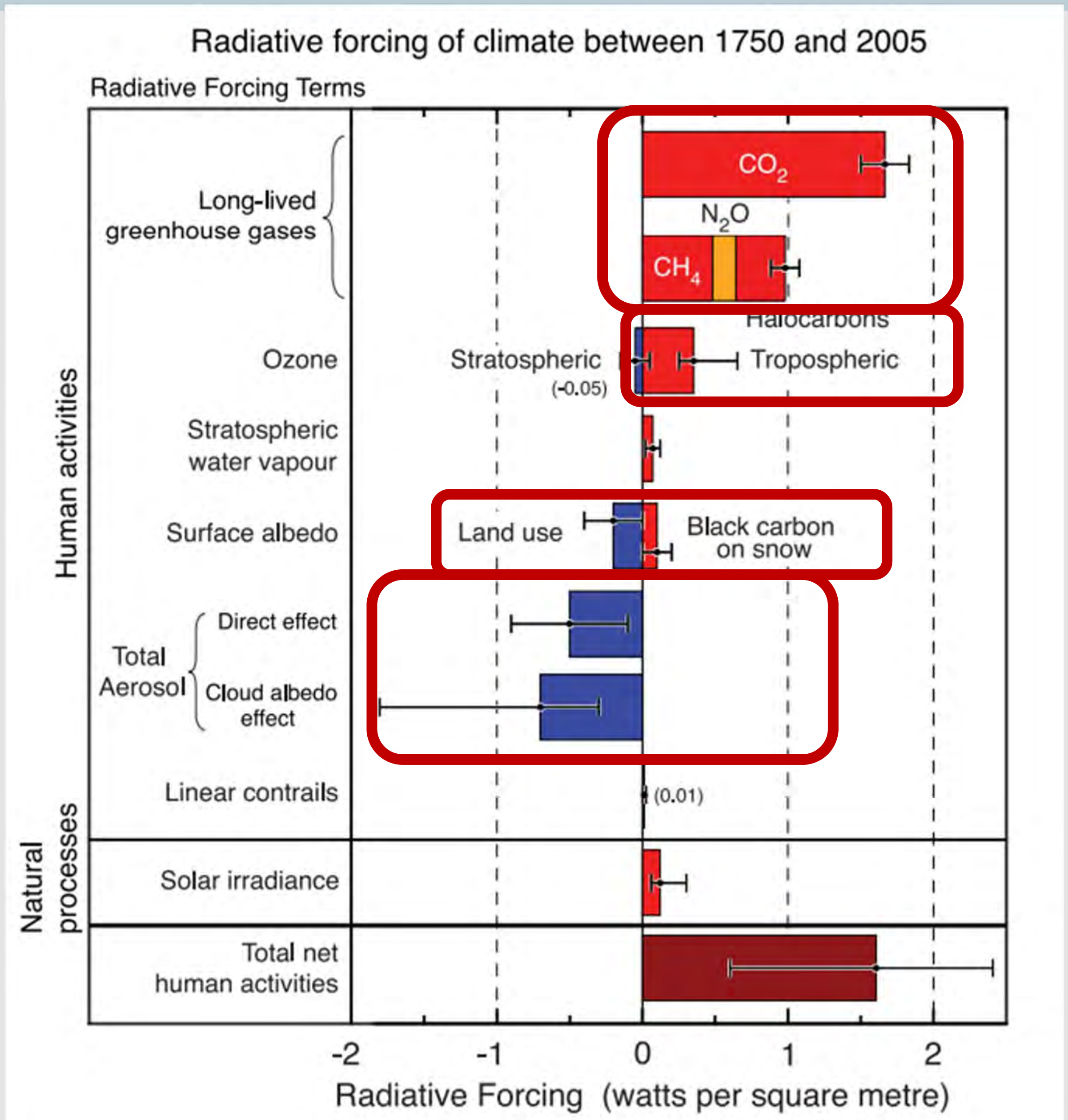
Fires emit significant amounts of trace gases and particulate matter to the atmosphere. These emissions include greenhouse gases, such as $CO_2$ and methane, reactive gases that include a suite of non-methane organic compounds, and various particulate species, including black and organic carbon. Quantifying these emissions and constraining our understanding of their impacts on the atmosphere continues to be an on-going challenge. Recent advances in measurement techniques, remote sensing observations and modeling tools have enabled much better constraints on these processes, yet, large uncertainties remain. There are feedbacks between the fire and climate systems that can control the emissions from fires. Further, once in the atmosphere, fire emissions not only impact atmospheric composition and air quality, but can also influence the climate system in various ways. For example, particulate matter emitted to the atmosphere from fires can have direct radiative effects that can influence local meteorology, as well as processes that control atmospheric chemistry. This talk will address the various emissions from fires to the atmosphere and their controls, including climatic controls. The impacts of fires on the climate system will also be highlighted and the results from recent studies presented.

# Radiative Forcing of Climate




**1. Long-lived GHG emissions**

**3. Ozone production**

**4. Change in surface properties**

**2. Short-lived climate forcers: particles**

IPCC 2007

# Fires Impacts on the Climate System

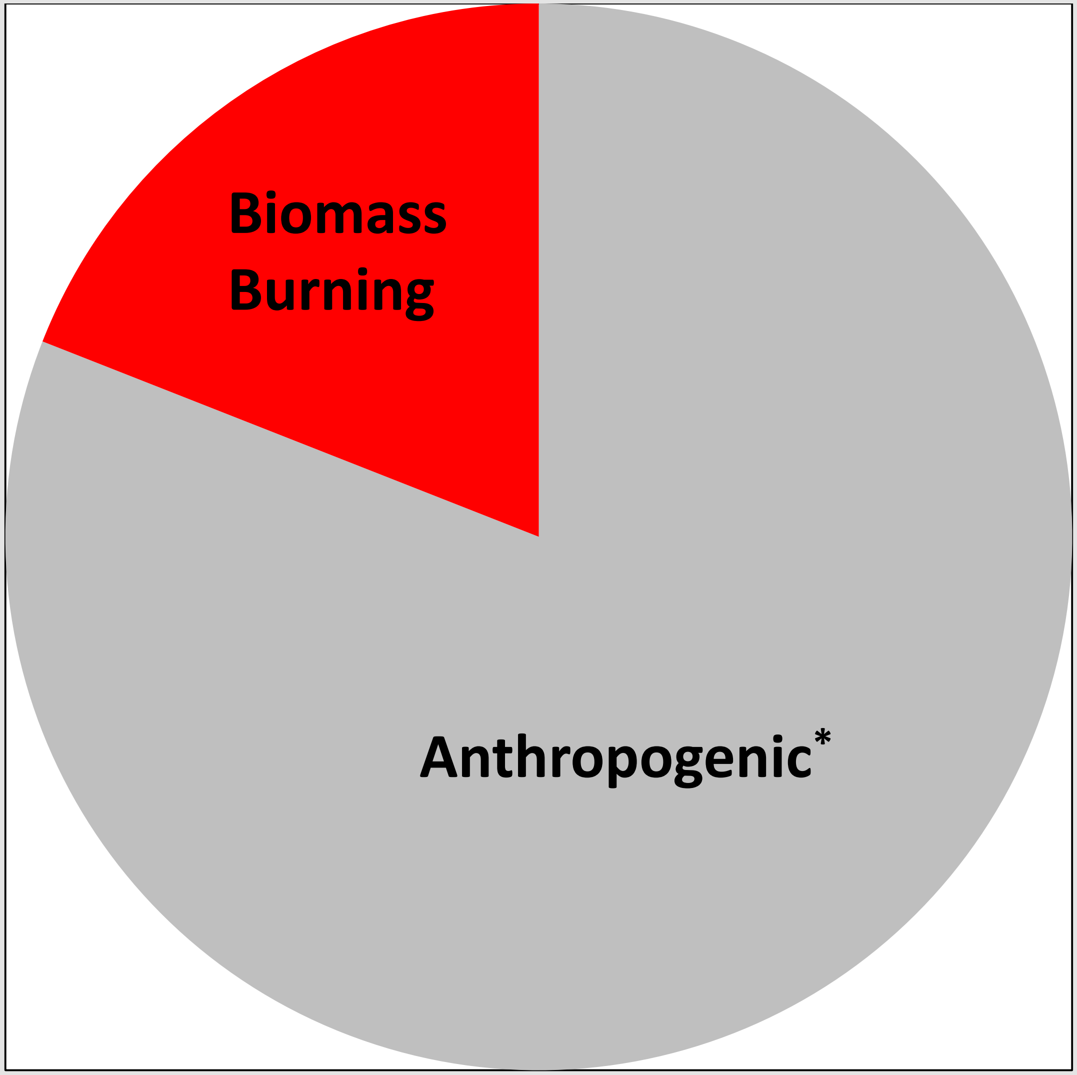
1. Emission of long lived greenhouse gases
   - $CO_2$
     - ~ 6-7 Pg $CO_2$ annually released to atmosphere from open burning
   - $N_2O$
   - $CH_4$

# Global $CO_2$ Emissions Estimates

2007 Global $CO_2$ emissions

*Total:*

38 Pg $CO_2$

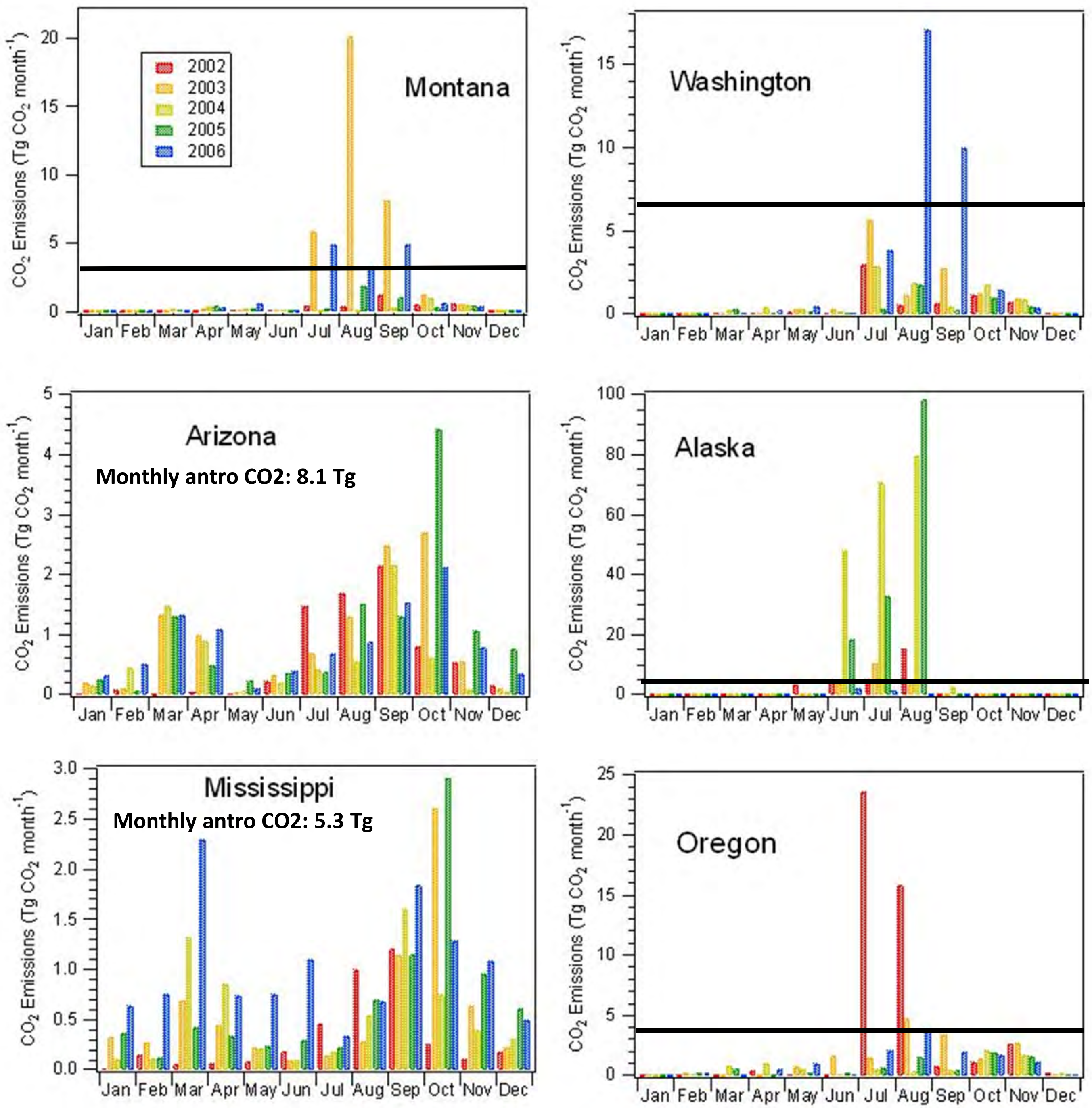



*Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement

*Source:* Carbon Dioxide Information Analysis Center, Environmental Sciences Division, Oak Ridge National Laboratory, Tennessee, U.S.

# $CO_2$ Emissions from open fires across the U.S.

***Note:***
**temporal & spatial variability**




**Wiedinmyer and Neff, *CBM*, 2007**

**Black lines represent monthly $CO_2$ emissions from fossil fuel combustion (U.S. Energy Information Administration)**

# Fires Impacts on the Climate System

1. Emission of long lived greenhouse gases
   - $CO_2$
     ~ 6-7 Pg $CO_2$ annually released to atmosphere from open burning
   - $N_2O$
   - $CH_4$

2. Direct emission of short-lived climate forcers
   - Black Carbon
   - Particulate organic matter

3. Production of tropospheric ozone and secondary organic particulate matter

# Emissions from Fires

Carbon Dioxide ($CO_2$)
Methane ($CH_4$)
Nitrous Oxide ($N_2O$)

Carbon Monoxide (CO)

Acetylene ($C_2H_2$)
Ethylene ($C_2H_4$)
Ethane ($C_2H_6$)
Propadiene ($C_3H_4$)
Propylene ($C_3H_6$)
Propyne ($C_3H_4$)
Propane ($C_3H_8$)
n-Butane ($C_4H_{10}$)
1-Butene ($C_4H_8$)
1,3-Butadiene ($C_4H_6$)
n-Pentane ($C_5H_{12}$)
3-Methyl-1-Butene ($C_5H_{10}$)
Isoprene ($C_5H_8$)
Cyclopentane ($C_5H_{10}$)
n-Hexane ($C_6H_{14}$)
Heptane ($C_7H_{16}$)
Benzene ($C_6H_6$)
Toluene ($C_6H_5CH_3$)
Xylenes ($C_8H_{10}$)
Ethylbenzene ($C_8H_{10}$)
1,3,5-Trimethylbenzene ($C_9H_{12}$)
α-Pinene ($C_{10}H_{16}$)

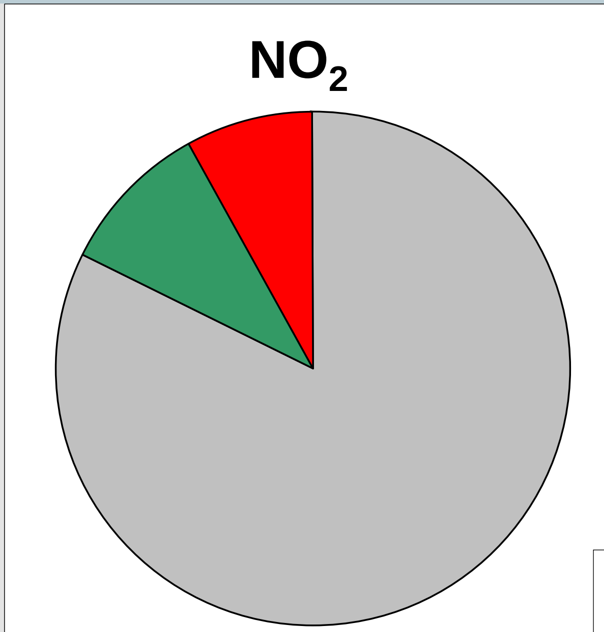
Ethanol ($CH_3CH_2OH$)
Methanol ($CH_3OH$)
Phenol ($C_6H_5OH$)
Formaldehyde (HCHO)
Glycolaldehyde ($C_2H_4O_2$)
Acetaldehyde ($CH_3CHO$)
Acrolein ($C_3H_4O$)
Furaldehydes
Propanal ($C_3H_6O$)
Acetone ($C_3H_6O$)
Methyl Vinyl Ether ($C_3H_6O$)
Methacrolein ($C_4H_6O$)
Crotonaldehyde ($C_4H_6O$)
2,3-Butanedione ($C_4H_6O_2$)
Furan ($C_4H_4O$)
3-Methylfuran ($C_5H_6O$)
Formic Acid (HCOOH)
Acetic Acid ($CH_3COOH$)

Methyl Bromide ($CH_3Br$)
Methyl Iodide ($CH_3I$)
Trichloromethane ($CHCl_3$)

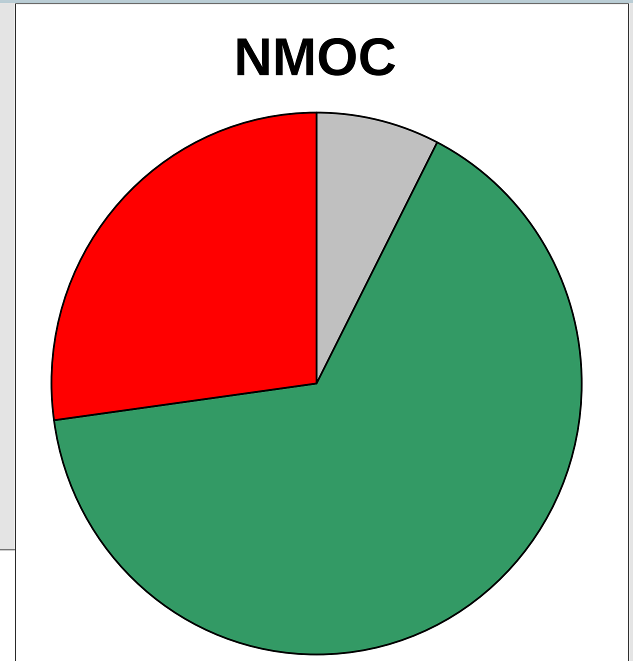
Hydrogen Cyanide (HCN)
Methyl Nitrate ($CH_3ONO_2$)
Ethyl Nitrate ($C_2H_5NO_3$)
Ammonia ($NH_3$)
Hydrogen ($H_2$)
Sulfur Dioxide ($SO_2$)
Nitrous Acid (HONO)
Nitrogen Oxides ($NO_x$ as NO)

Total Particulate Carbon
Total Suspended Particulate (TSP)
$PM_{2.5}$
$PM_{10}$
Black Carbon (BC)
Organic Carbon (OC)
Oxylate ($C_2O_4$)
Nitrate ($NO_3$)
Phosphate ($PO_4$)
Sulfate ($SO_4$)
Ammonium ($NH_4$)
Cl
Ca
Mg
Na
K

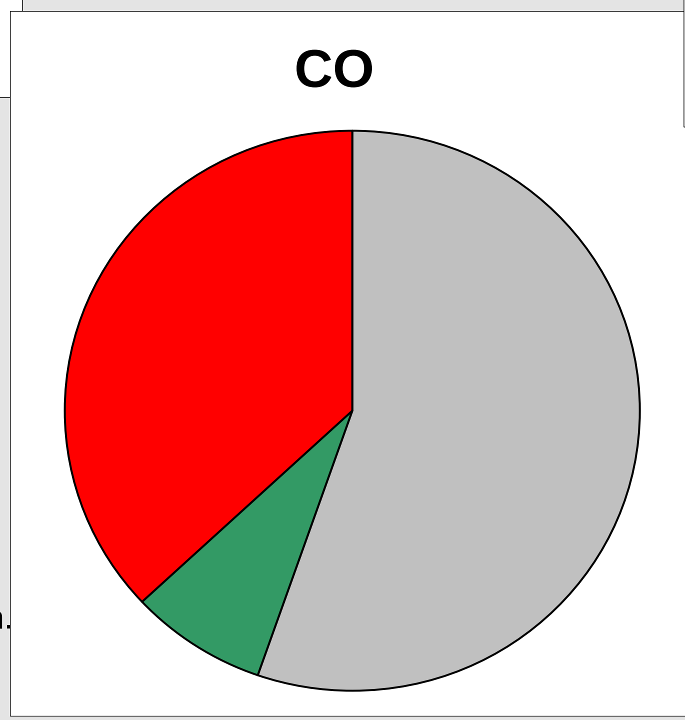
# Global Trace Gas Emissions Estimates





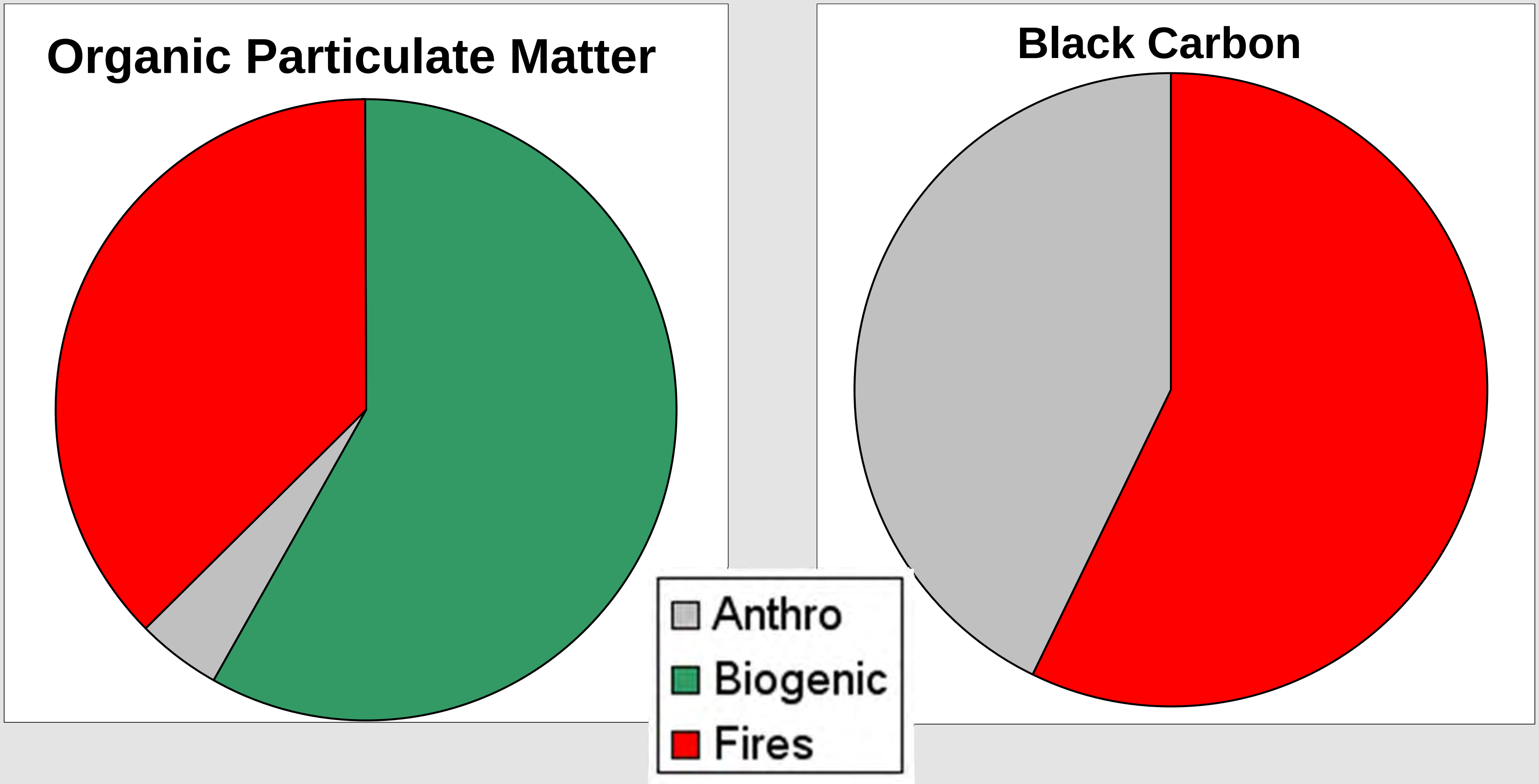



Yokelson et al., ACP, 2008



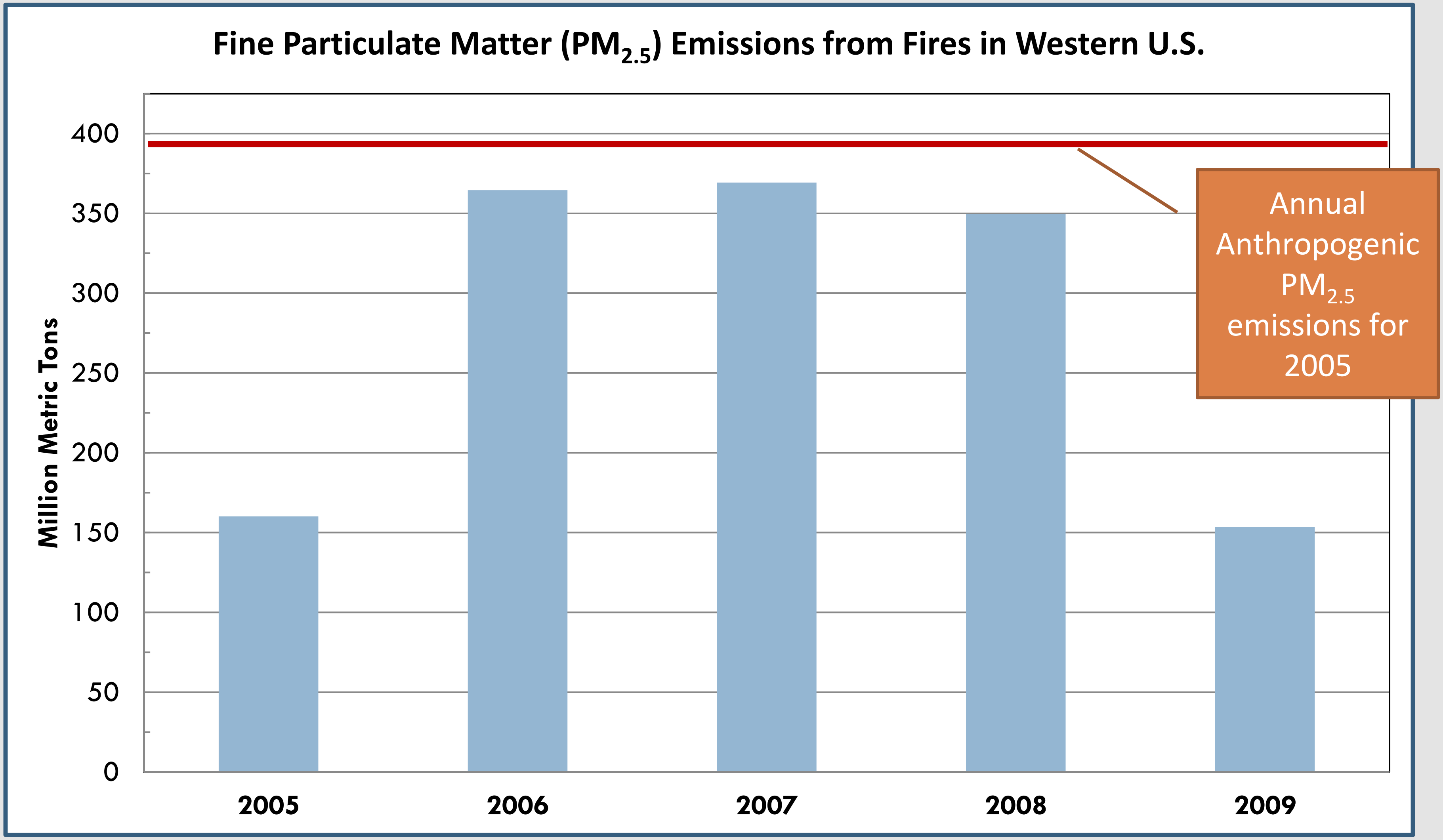

EDGARFT2000
Yan et al, GBC, 2005
Guenther et al., 1995; 2006; pers. comm.
GFEDv2 (van der Werf et al., 2006)
Andreae and Merlet, GBC, 2001

# Global Particulate Matter Emissions

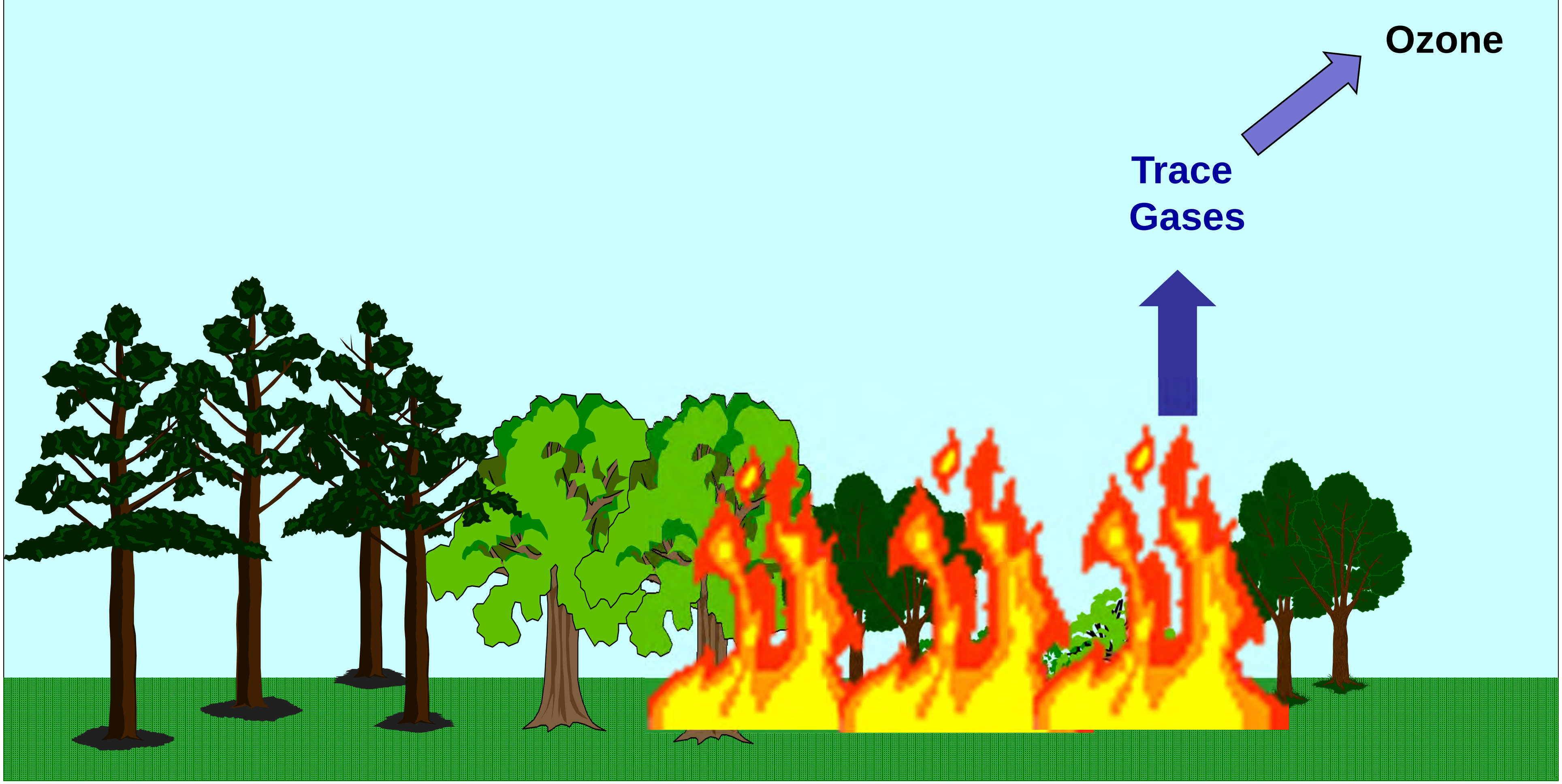



Andreae and Rosenfeld, *Earth Science Reviews*, 2008

# Emission Estimates in the U.S.



# Atmospheric Impacts of Emissions



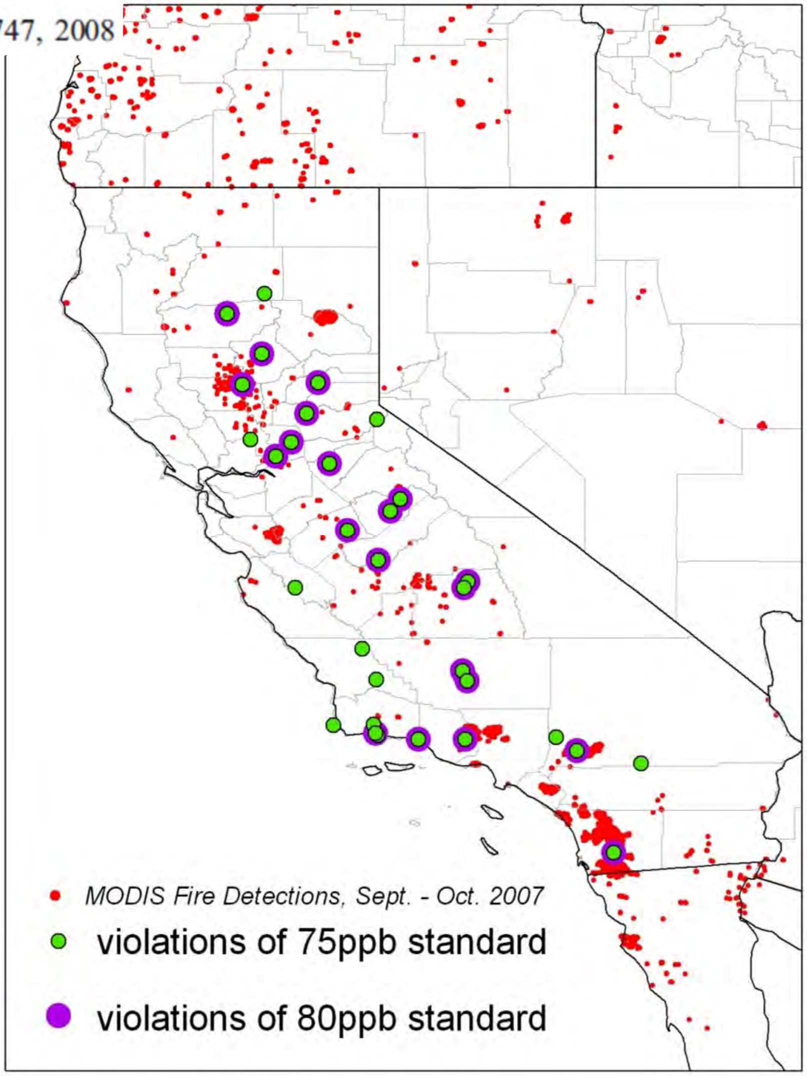
# Fire Emissions and Ozone

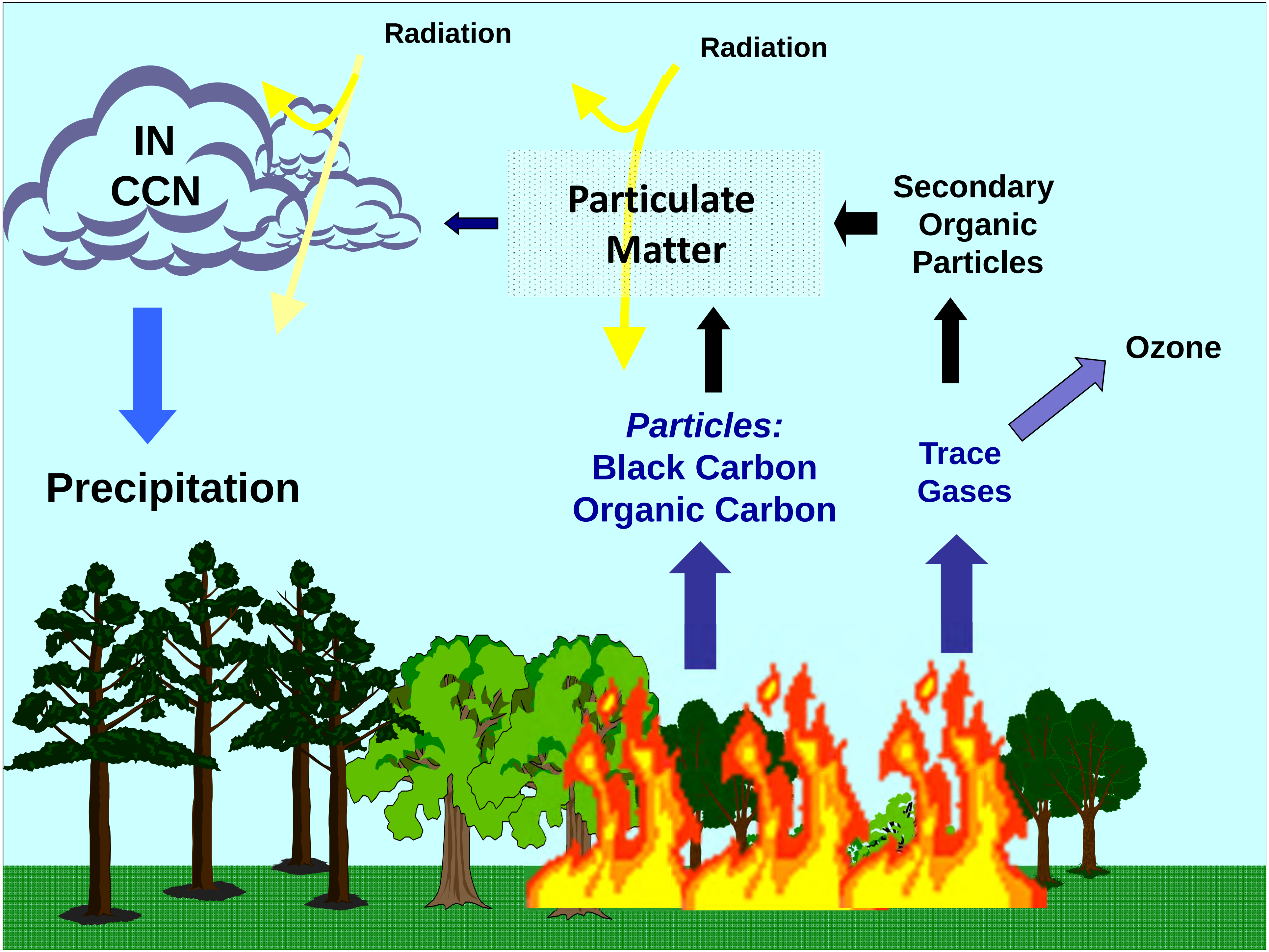
Impacts of the fall 2007 California wildfires on surface ozone: Integrating local observations with global model simulations

G. G. Pfister,[1] C. Wiedinmyer,[1] and L. K. Emmons[1]

GEOPHYSICAL RESEARCH LETTERS, VOL. 35, L19814, doi:10.1029/2008GL034747, 2008

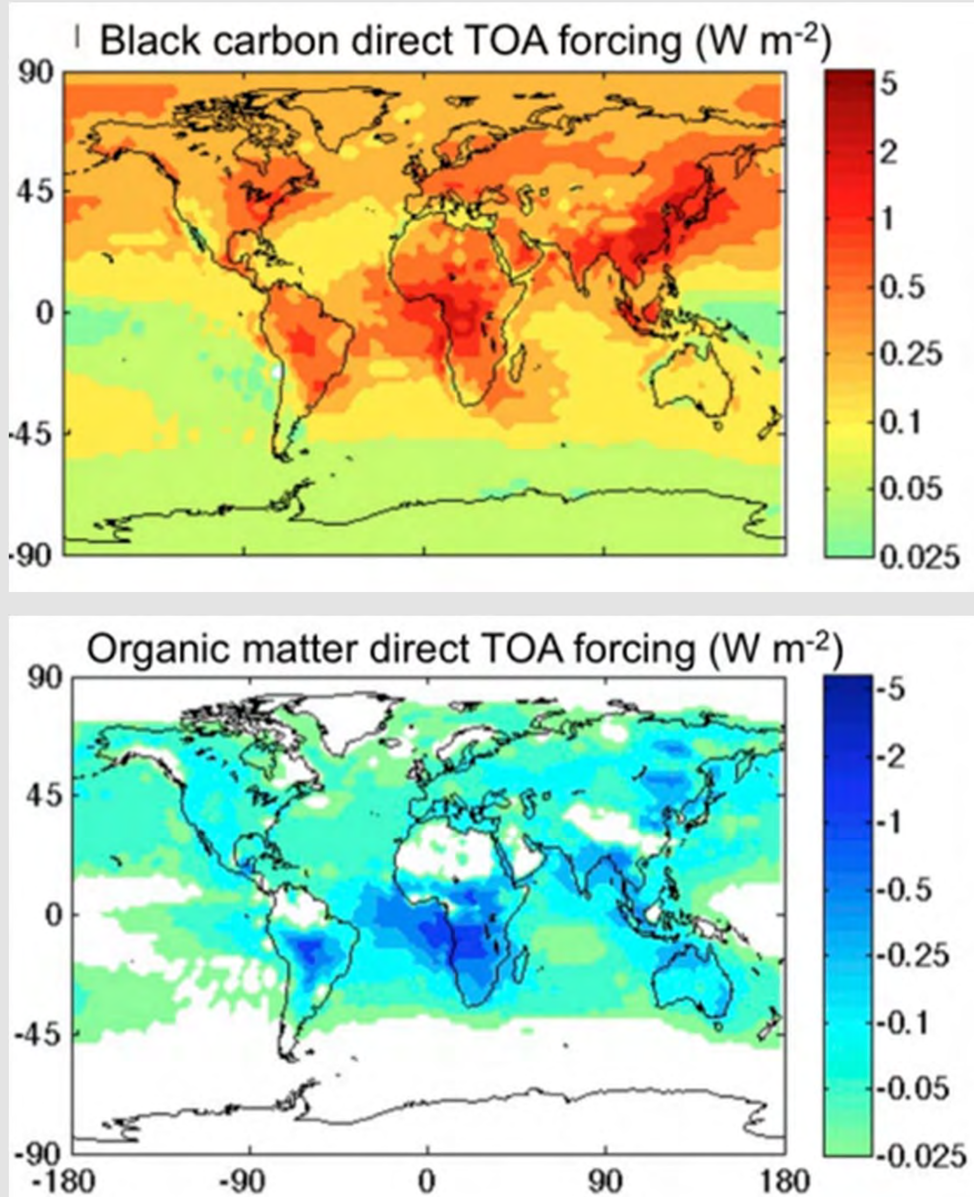
Violations in $O_3$ health standards in rural areas happened three times more likely because of pollution from the wildfires.




Radiation
Radiation
IN
CCN
Particulate
Matter
Secondary
Organic
Particles
Ozone
Precipitation
Particles:
Black Carbon
Organic Carbon
Trace
Gases

# Radiative Forcing of Particulate Carbon

Total Black Carbon and Particulate Organic Matter Top of the Atmosphere (TOA) forcing

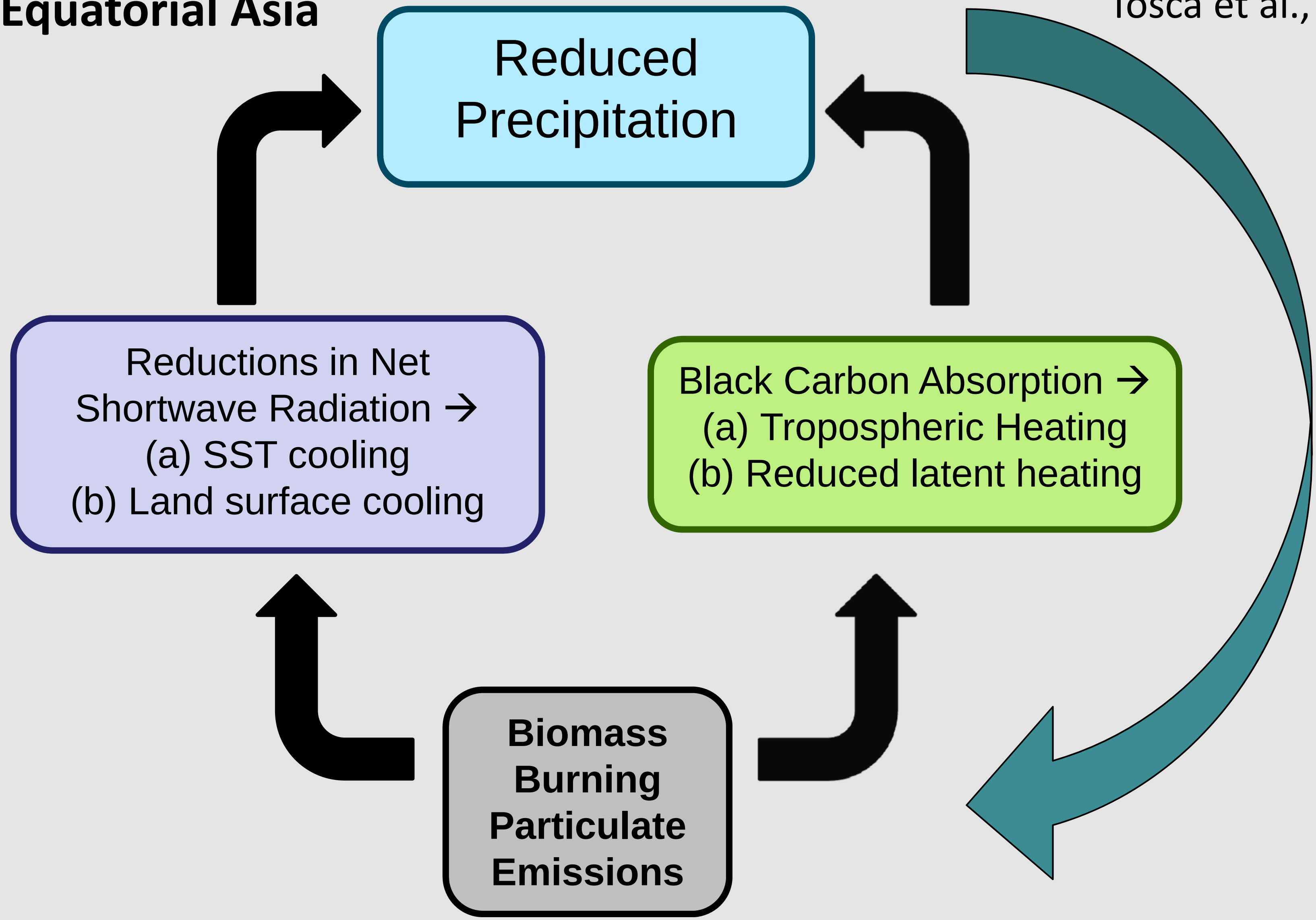



Bond et al., *ACP,* 2011

# Regional Climate Feedbacks from Fires

**Equatorial Asia**

Tosca et al., *ACP,* 2010




*During El Nino- drought and increased fire emissions*

# Regional Climate Feedbacks from Fires

INHIBIT PRECIPITATION

↑

INCREASE # CLOUD DROPS

↑

DECREASE IN DROP SIZE

↑

INCREASE CCN

↑

SMOKE

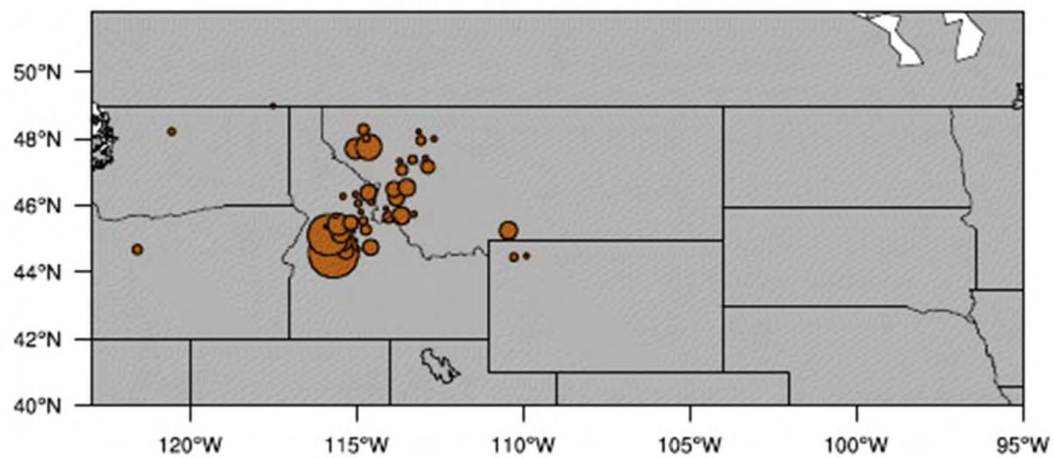
(e.g., Andreae et al., 2004; Rosenfeld 1999)

# Regional feedbacks to weather and chemistry

Use coupled weather-chemistry model to investigate the feedbacks between the fire emissions, weather, and chemistry


a). Fires captured on August 13, 2007 by MODIS

PM2.5 (ranging from 0.2 to 3.0 ug/m3 m/s)




Jiang, Wiedinmyer and Carlton, *in preparation*

# Regional feedbacks to weather and chemistry

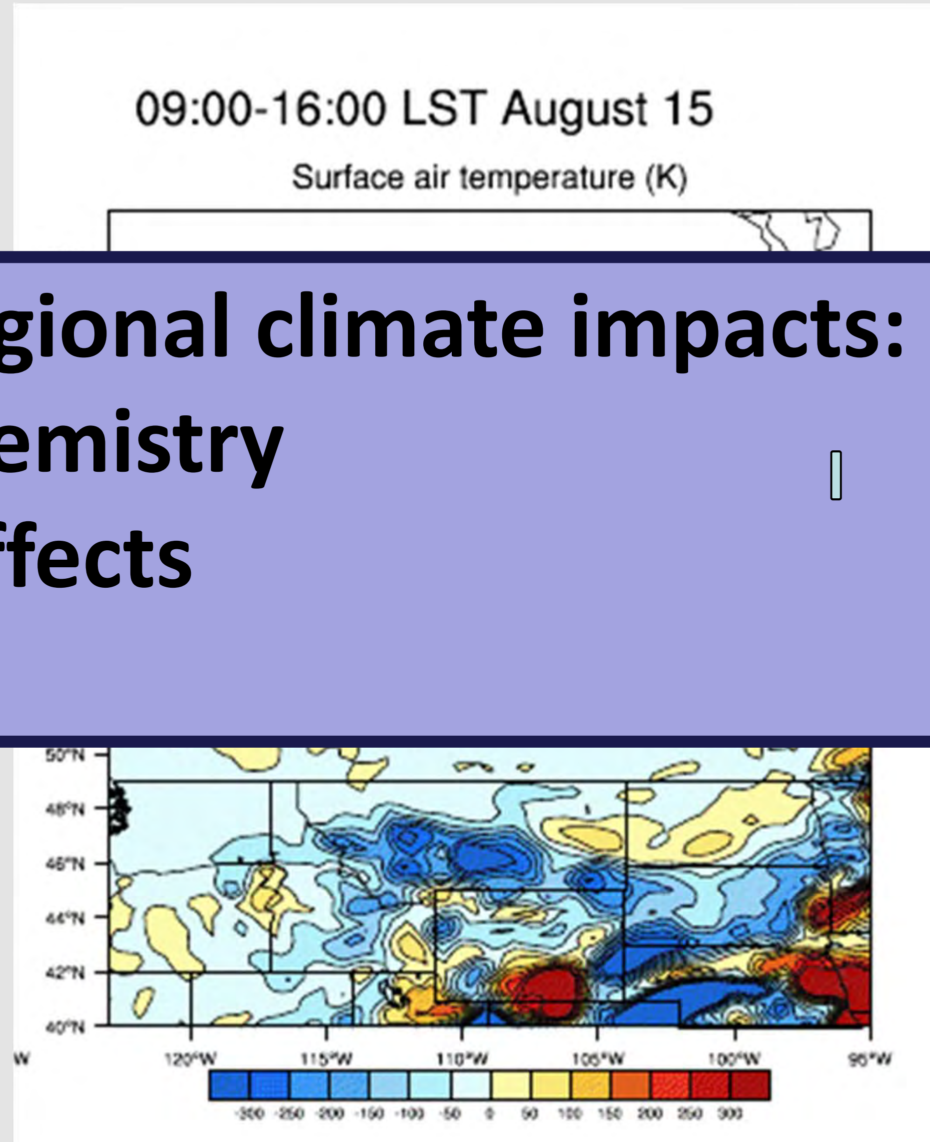
- Inclusion of fire particulate emissions:

**Fire emissions have regional climate impacts:**

- **Meteorology and chemistry**
- **Local and regional effects**
- **Short-lived impacts**

water vapor mixing ratio

  – Change ozone concentrations




Jiang, Wiedinmyer, and Carlton, *in preparation*

# Fires Impacts on the Climate System

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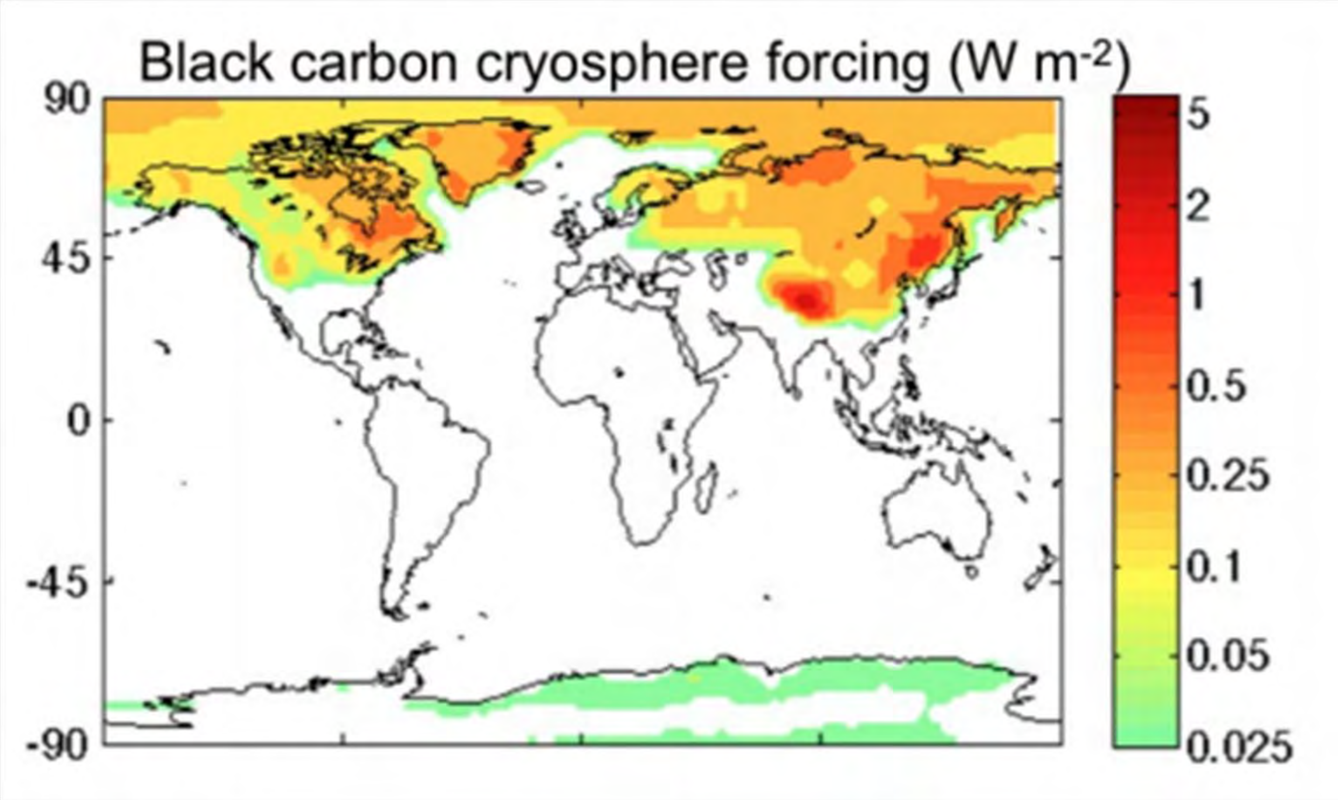
2. Emission of short-lived climate forcers
   - Black Carbon
   - Particulate organic matter

3. Production of tropospheric ozone and secondary organic particulate matter

4. Changes in land surface properties
   - Black carbon on snow
   - Albedo

# Radiative Forcing of Black Carbon on Snow

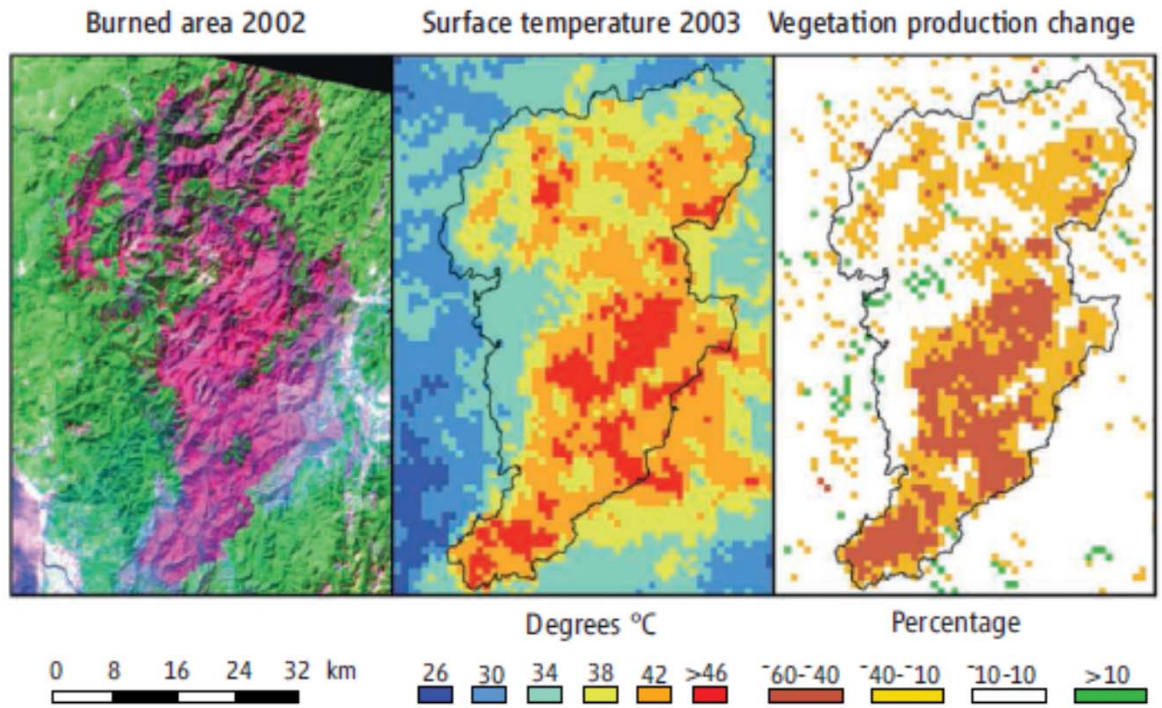



Bond et al., *ACP,* 2011

# Fire impacts on climate: Land Cover Change

Post Fire Impacts:

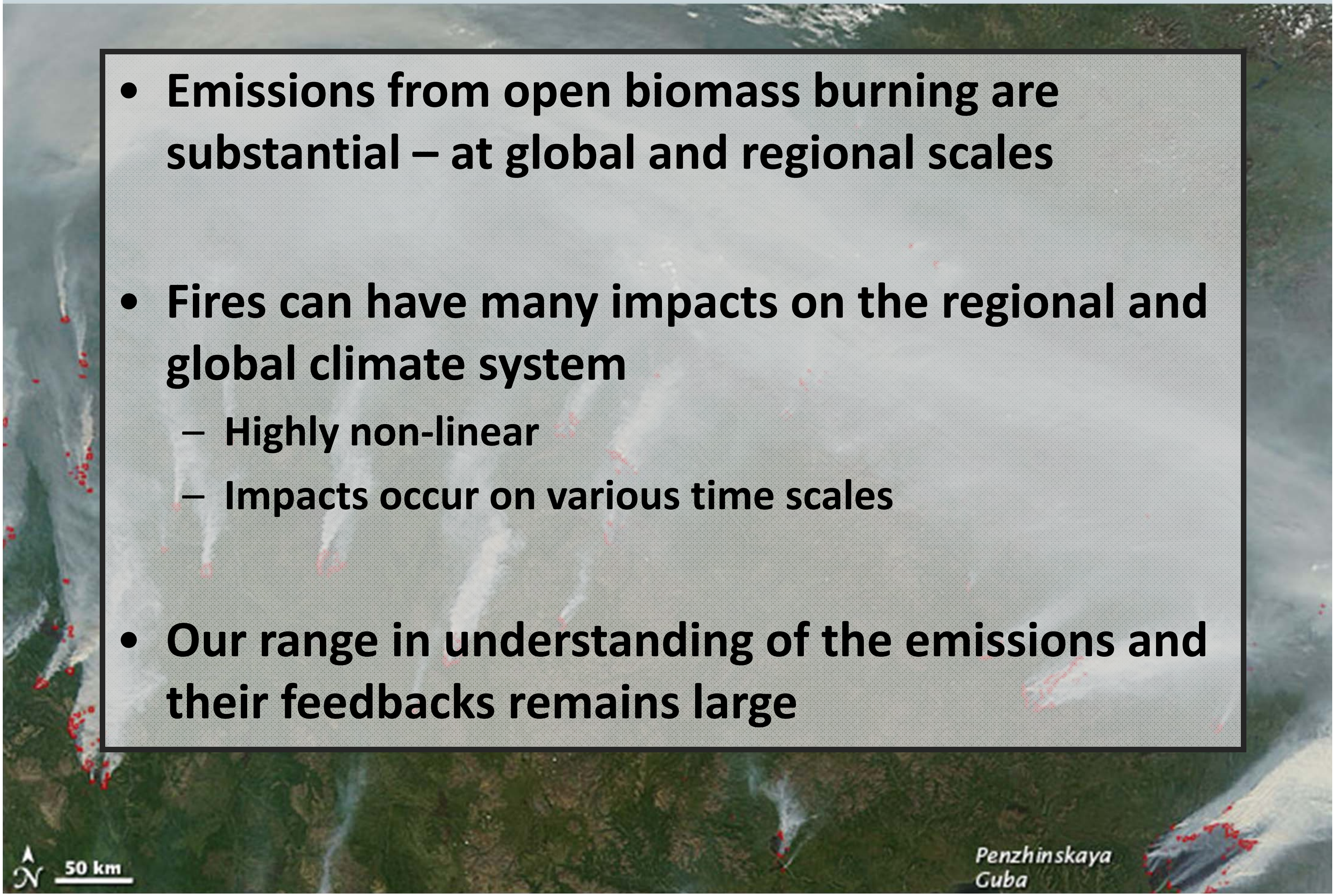
- Surface temperature
- Vegetation production
- Albedo




**Impact of fire disturbance on land surface energy and carbon balances.** In the summer of 2002, the Biscuit Fire in Oregon destroyed 2000 km$^2$ of temperate evergreen forests (**left**). A Moderate Resolution Imaging Spectroradiometer (MODIS) satellite image taken on 28 July 2003 (**middle**) shows land surface radiometric temperatures of 46° to 50°C in the area burned the summer before, whereas temperatures in the adjacent unburned forests range from 27° to 32°C. Annual vegetation production measured from MODIS (*4*) (**right**) was 20 to 60% lower in the burned area in 2003 to 2004 than before the wildfire.

Running, *Science*, 2008

# Concluding Remarks




- **Emissions from open biomass burning are substantial – at global and regional scales**
- **Fires can have many impacts on the regional and global climate system**
  - **Highly non-linear**
  - **Impacts occur on various time scales**
- **Our range in understanding of the emissions and their feedbacks remains large**

# Acknowledgements

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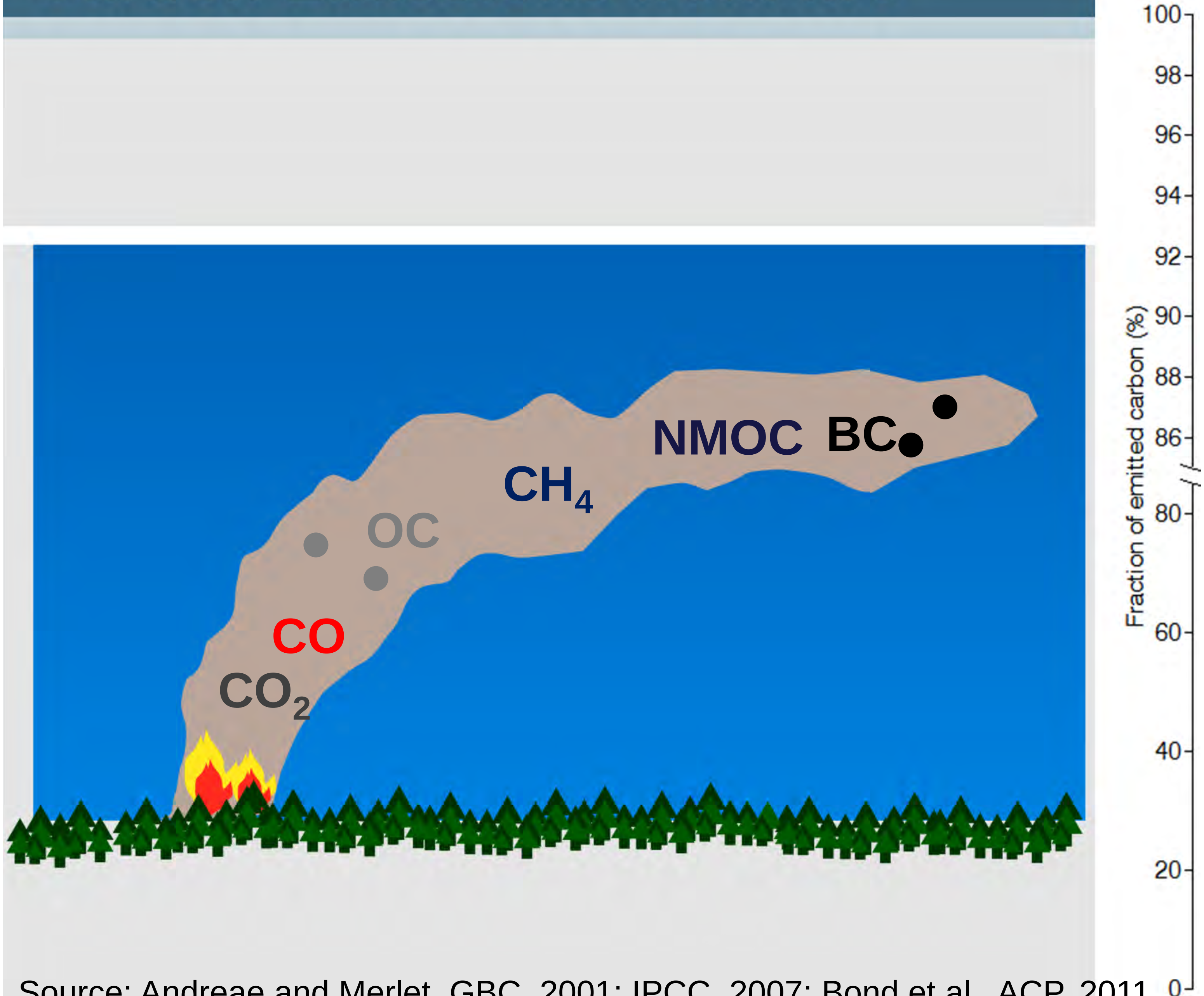
Xiaoyan Jiang (Los Alamos National Lab/NCAR)

Louisa Emmons, Gabi Pfister (NCAR)

Jason Neff (University of Colorado)

# Additional Slides

# Carbon Emissions from fire




Source: Andreae and Merlet, GBC, 2001; IPCC, 2007; Bond et al., ACP, 2011

# Aerosol effects

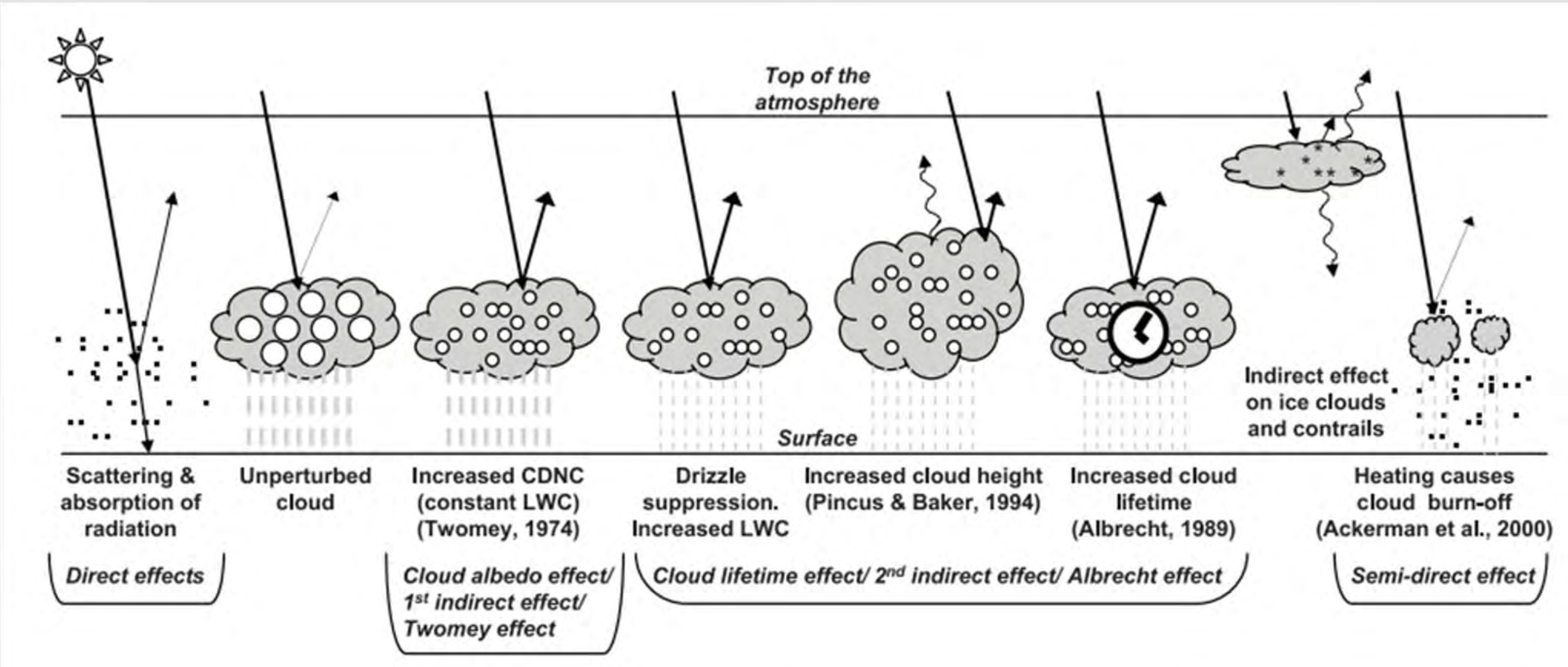
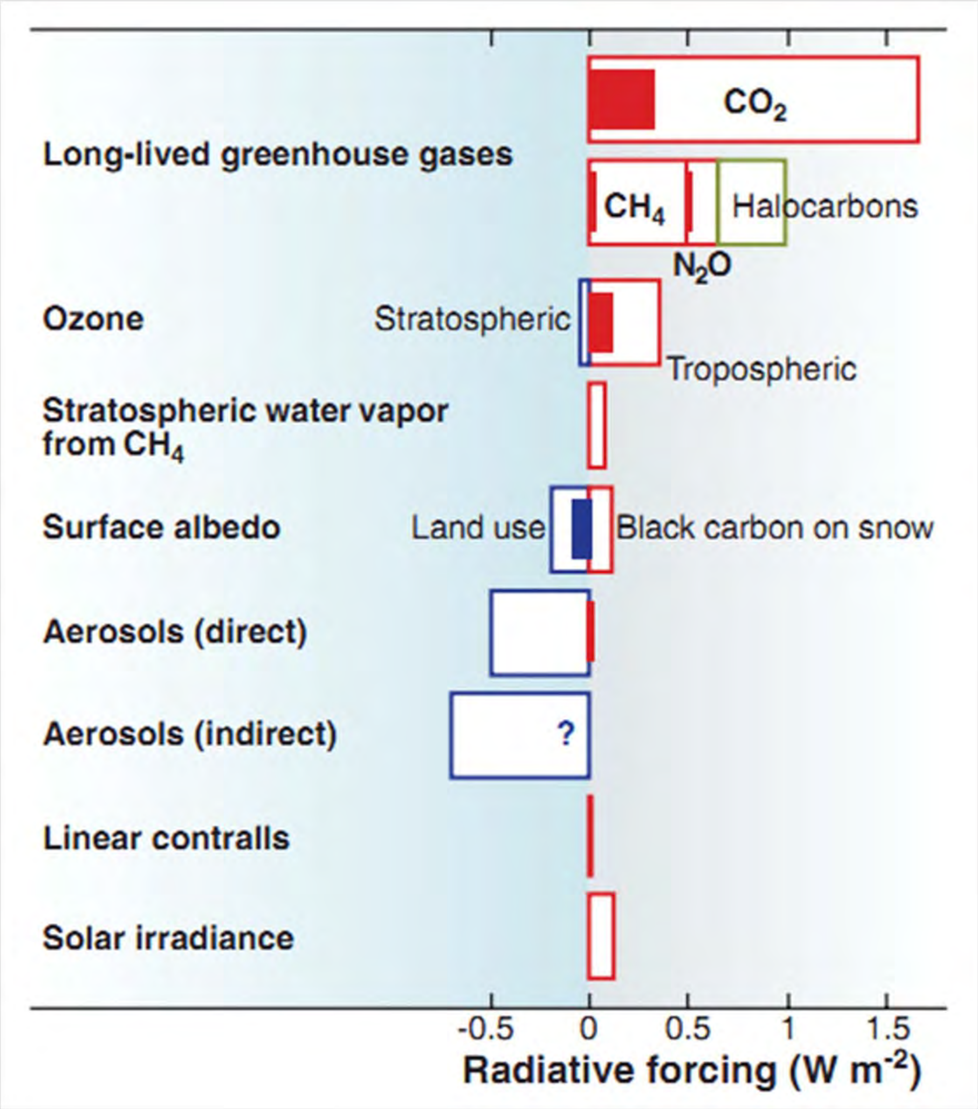



**Figure 2.10.** *Schematic diagram showing the various radiative mechanisms associated with cloud effects that have been identified as significant in relation to aerosols (modified from Haywood and Boucher, 2000). The small black dots represent aerosol particles; the larger open circles cloud droplets. Straight lines represent the incident and reflected solar radiation, and wavy lines represent terrestrial radiation. The filled white circles indicate cloud droplet number concentration (CDNC). The unperturbed cloud contains larger cloud drops as only natural aerosols are available as cloud condensation nuclei, while the perturbed cloud contains a greater number of smaller cloud drops as both natural and anthropogenic aerosols are available as cloud condensation nuclei (CCN). The vertical grey dashes represent rainfall, and LWC refers to the liquid water content.*

IPCC, 2007

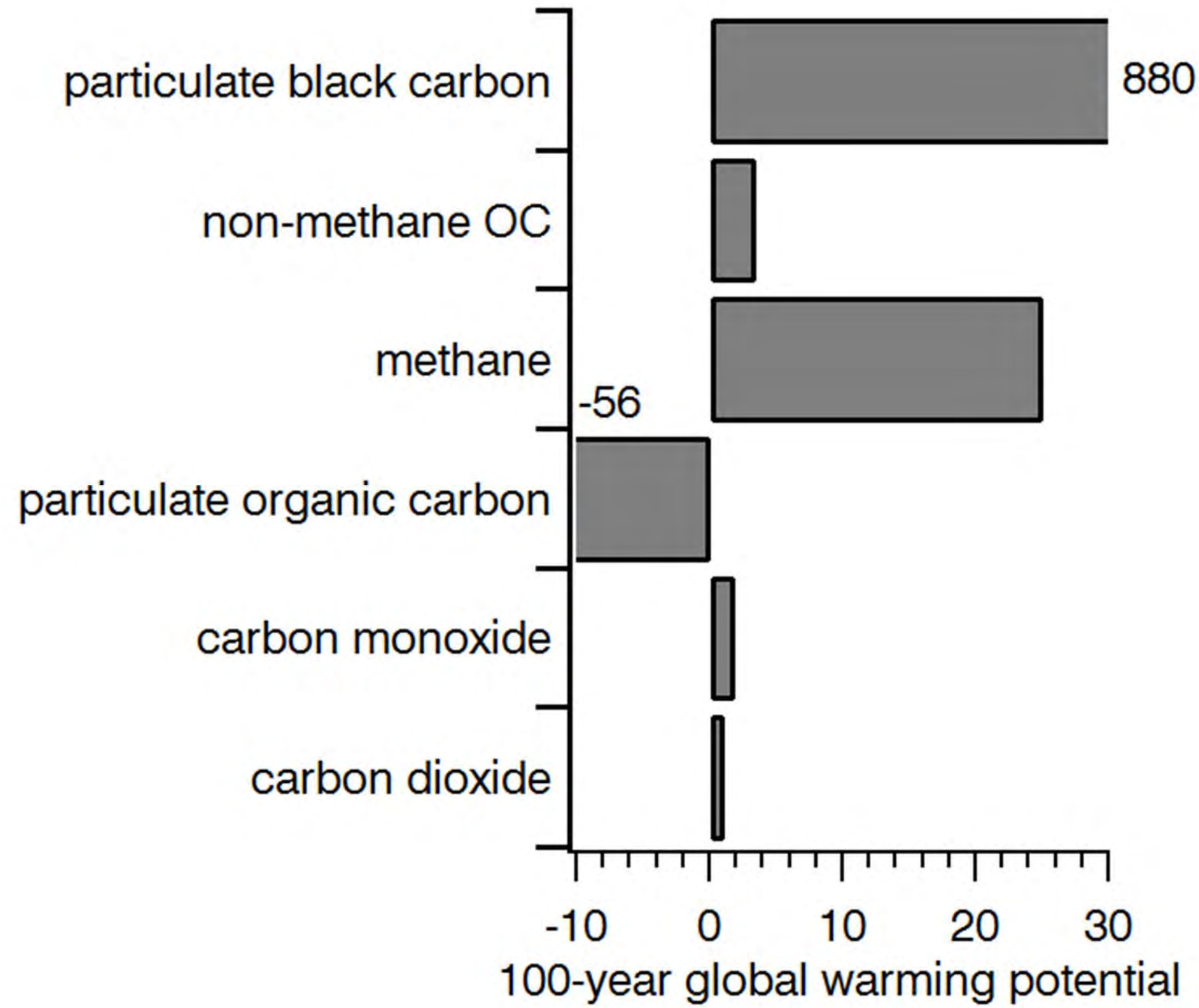
# Radiative Forcing of Climate




Estimated contribution of fire associated with deforestation to changes in radiative forcing

Bowman et al., *Science,* 2009

# Emissions from Fires: Global Warming Potential




***Andreae and Merlet, GBC, 2001; IPCC, 2007; Bond et al., ACP, 2011***

# Models to Predict Emissions from Fires

- Fire-Specific Models
  - Biscuit Fire (Campbell et al., 2007)

- Regional Models
  - North America (Wiedinmyer et al., *AE,* 2006)
  - Asia (Song et al., *ERL,* 2010)
  - Western Africa (Liousse et al., 2010)
  - Western U.S. (Urbanski, *ACPD,* 2011)

- Global Models
  - GFED (van der Werf et al., *AC&P,* 2010)
  - FINN (Wiedinmyer et al., *GMD*, 2011)

# Estimating Emissions from Fires

$$\text{Emission}_i = f(ef_{i}, \text{Biomass Burned})$$

**Emission Factor**

- **Vegetation**
  - **Type**
  - **Condition**
- **Fire**
  - **Intensity**

**Biomass Burned**

- **Vegetation**
  - **Type**
  - **Condition**
  - **Density**
  - **Loading**
- **Fire**
  - **Intensity**
  - **Duration**

# Global Emissions from Open Biomass Burning

| | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|
| **$CO_2$** | 7590 | 7723 | 7275 | 6433 | 6886 |
| **$CH_4$** | 18 | 20 | 18 | 16 | 17 |
| **CO** | 375 | 400 | 372 | 330 | 347 |
| **NMOC** | 81 | 92 | 81 | 71 | 75 |
| **NO** | 13 | 13 | 12 | 11 | 12 |
| **$SO_2$** | 2 | 3 | 2 | 2 | 2 |
| **OC** | 23 | 24 | 23 | 21 | 22 |
| **BC** | 2 | 2 | 2 | 2 | 2 |

* Emissions in Tg $year^{-1}$

Wiedinmyer et al., *GMD*, 2011